ULTRA-HIGH RESOLUTION OBSERVATION-DRIVEN LAND MODELING NEEDED TO ENABLE THE DEVELOPMENT OF GLOBAL CLOUD RESOLVING EARTH SYSTEM MODELS

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The relatively crude representation of cloud processes in global climate models has long been recognized as a primary source of uncertainty in climate change predictions. It is well known that the high-resolution time and space complexity of land surface phenomena have significant influence on atmospheric boundary layer turbulence and cloud processes. Scale truncation errors, unrealistic physics formulations, and inadequate coupling between surface fluxes and the overlying atmosphere cause serious systematic errors. Standard subgrid-scale tiling approaches are not able to adequately represent observed heterogeneity and boundary-layer interaction (Bosilovich, 2002), which means that fine-scale model representations are required. The inability to explicitly account for the considerable spatial and temporal variability in terrain topography, surface properties, rainfall, and net surface radiation constitute an organic weakness of current climate models and a cause for substantial errors in model simulations of near-surface climate over land.

Therefore, the land surface research community must progress toward a fully process-scale resolving model of land surface hydrology, atmospheric dynamics, and cloud processes over the global domain (Tao et al., 2003). We must integrate all obviously interdependent land-atmosphere processes into a common ultra-resolution (100s of meters) framework for Earth system modeling, through fusion of traditional land surface hydrology modules with boundary-layer turbulence and cloud process modules. Decisions regarding the model formulations must be guided to the greatest extent possible by the use of observations, as prescribed input, data assimilation constraints, validation or relevance to applications or decision-making.

To this end, we envision two, eventually convergent, paths toward fully interactive land-atmosphere coupling: (1) In the near-term, implement traditional cloud parameterization and atmospheric turbulence schemes and implicitly couple those (through the atmospheric circulation) to patch-based land models at highest possible resolution; and (2) In the long-term, develop true global process-resolving coupled land-atmosphere models in a phased approach, starting with (a) off-line land-cloud process resolving studies, then progressing to (b) land-cloud super-parameterizations based on sampling the relevant process scales, (c) nested land-cloud resolving models in a Global Circulation Model (GCM) framework, and finally (d) to a true global ultra-high-resolution global cloud-land process resolving model. These two paths will eventually converge when computing power allows the resolution of the Earth system model to overlap the resolution of the global cloud resolving model.

The unprecedented availability of new global land-surface remote sensing data over the past decade should be a fundamental driver for the development of new scientific understanding and modeling innovations. Land data assimilation systems have been developed that use sophisticated land surface models to ingest satellite and ground-based observations, as parameters, forcing, and data for assimilation, in order to produce the best possible fields of land surface states and fluxes. The multi-institution North American Land Data Assimilation System (NLDAS) project was the first to embrace this concept (Mitchell et al., 1999). Its success led to the development of Global LDAS (GLDAS) (Houser and Rodell, 2002; Rodell et al., 2004; http://ldas.gsfc.nasa.gov) through the joint effort of scientists at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center and the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP).

The 1/4-degree resolution, high quality, near-real time and retrospective output fields that have resulted from GLDAS (see the figure at the bottom of page 1), the first of their kind, are providing the basis for global scale studies of the hydrological cycle and meteorological processes. In addition, GLDAS surface state fields are being tested in weather and climate model initialization studies at NCEP and NASA's Global Modeling and Assimilation Office (GMAO), where GLDAS soil moisture fields have been shown to improve the predictability of seasonal precipitation, and are being tested as input to water management decision support systems.

The Land Information System (LIS) Project (http://lis.gsfc.nasa.gov) has streamlined and parallelized the GLDAS code and has executed 1-km resolution, global simulations using 3 different land models on high performance computing platforms. LIS incorporates Assistance for Land surface Modeling Activities (ALMA) and Earth System Modeling Framework (ESMF) standards to facilitate inter-operation with other Earth system models. LIS also employs a Grid Analysis and Display System – Distributed Oceanographic Data System (GrADS-DODS) server framework which allows for seamless access to large observational databases. LIS is currently being coupled to the Weather Research and Forecasting (WRF) and Goddard Cumulus Ensemble (GCE) models to explore surface-layer feedback effects due to assimilation. However, there remain great challenges in representing process-scale land-surface dynamics in Earth system models, such as the need for LSM-compatible groundwater, glacier, ice sheet, and wetland models and schemes for simulating the effects of dams, agriculture, and irrigation on land surface hydrology.

New global remote sensing observations provide the foundation for the development of a new generation of Earth system models that will explicitly resolve weather and climate relevant physical, chemical and biological processes, in order to improve dramatically the understanding and prediction of weather and climate. This will require, among other things, an ultra-high-resolution observation-driven land surface model with process-scale hydrology and biogeochemistry dynamics that is implicitly coupled to high-resolution boundary-layer turbulence and cloud microphysics parameterizations. These innovations will be invaluable for a wide range of applications, including satellite data assimilation, observation system design, weather forecasting and climate simulation.